the air, and is so soluble that a vast amount of it is required to saturate even a small quantity of serum.

Various other salts have been examined.   Many that are not very soluble produce no effect at all ; among these may be mentioned potassium nitrate, potassium sulphate, potassium chloride, potassium chlorate, ammonium chloride.

Others, like sodium chloride and sodium nitrate, precipitate globulin completely, but slowly, in simple serum.   Sodium nitrate precipitates serum-albumin completely, but slowly, after saturation with magnesium sulphate.

Sodium nitrate has a very marked effect in lowering the heat-coagulation of a proteid.   Potassium nitrate acts similarly, but not nearly to so great an extent as sodium nitrate.

Fuller particulars concerning these various salts will be given when the experiments relating to them are completed.

The most important results that these researches show are as follows :—

(1.) That the albumin of serum can by the process of fractional heat-coagulation be shown to consist of three separate proteids, which may be called provisionally serum-albumin numbers 1, 2, and 3 (to avoid a multiplicity of terms).   In certain animals only two of these are present.

(2.) That the precipitates described by Fredericq as occurring in serum at temperatures below 70° C. have, in this series of experiments, in which some hundreds of heat-coagulation determinations have been made, been found never to occur.

(3.) That the albumins of serum can be completely precipitated after saturation with magnesium sulphate and removal of the serum-globulin by saturation with sodium sulphate.

(4.) That potassium acetate, added in excess to solution of a proteid, *e.g.*, serum or solution of egg-albumin, completely precipitates the proteid therefrom without coagulating it.

IV. " The Influence of Stress and Strain on the Physical Properties of Matter."*   Part I.   Moduli of Elasticity— *continued*.   Relations between Moduli of Elasticity, Thermal Capacity, and other Physical Constants.   By HERBERT TOMLINSON, B.A.   Communicated by Professor W. GRYLLS ADAMS, M.A., F.R.S.   Received May 28, 1884.

(Abstract.)

The thermal capacity of each of the wires already used for the

* The original title of the paper has been altered to the above, as being more exact in expression.

experiments on moduli of elasticity and electrical conductivity described in Parts I and II of this paper* was determined in the following manner :—The wires, which had been previously well annealed, were wound round a steel rod and so made into coils of length about 2 inches, inner diameter $\frac{3}{4}$ inch, and outer diameter $1\frac{3}{4}$ inches, the rod was then withdrawn and the coil inserted into a thin brass envelope. The envelope consisted of a hollow cylinder 2 inches in length and 2 inches in diameter, terminated at both ends by a truncated cone. One of the conical ends was closed and could be unscrewed so as to receive the coil of wire, and was, after the insertion of the coil, screwed on again. At the other extremity of the envelope was an aperture $\frac{3}{4}$ inch in diameter, through which a thermometer could be inserted, so that its bulb would lie along the axis and in the centre of the coil of wire. The brass envelope and the contained coil were heated in an air-chamber consisting of two concentric copper cylinders of equal length connected at their two ends, so as to enclose between them a layer of water $\frac{1}{4}$ inch thick. The length of the air-chamber thus formed was 14 inches, and the inner diameter $2\frac{1}{4}$ inches, so that the envelope could freely slide through the chamber. The two ends of the air-chamber, which was placed in a horizontal position, were closed by corks, through the centre of one of which passed a thermometer, and through a very small hole in the centre of the other was drawn a fine but strong thread attached with one extremity to the envelope, and with the other wound round a little piece of wood which prevented the thread from being dragged through the hole when the former was drawn tight. The envelope and contained wire were heated before immersion in the water of the calorimeter in one set of experiments to about 60° C., and in another set to about 100° C. The envelope served a double purpose, as it not only enabled compensation to be made for loss of heat during the transference of the wire from the air-chamber to the calorimeter, but also was of use in distributing the heat uniformly throughout the coil.

Preliminary observations were made for the purpose of ascertaining the rise of temperature which would be caused by immersing the heated envelope only in the water of the calorimeter.

Every precaution was taken both with regard to the instruments themselves and the mode of using them to avoid error, and the formulæ given below may be received with great confidence.

It will be seen that the thermal capacity of all the metals examined increased with the temperature, a result which we find confirmed by the observations of other investigators.

The thermal capacities of the alloys platinum-silver, and German-silver are, within the limits of error, exactly the same as those

* " Phil. Trans.," Part I, 1883, p. 1.

Metal.	Density at 20° C., density of water at 4° C. = 1.	Formulæ for the number of thermal units required to raise the temperature of unit mass from 0° C. to $t°$ C. Thermal capacity of water at 0° C. = 1.	Thermal capacity per unit mass at $t°$ C.
Aluminium	2·731	$·20700t + ·0001152t^2$	$·20700 + ·0002304t$
Iron	7·759	$·10601t + ·0000701t^2$	$·10601 + ·0001402t$
German silver	8·632	$·09411t + ·0000053t^2$	$·09411 + ·0000106t$
Zinc	7·138	$·09009t + ·0000374t^2$	$·09009 + ·0000748t$
Copper	8·851	$·09008t + ·0000324t^2$	$·09008 + ·0000648t$
Silver.............	10·464	$·05466t + ·0000218t^2$	$·05466 + ·0000436t$
Tin...............	7·264	$·05231t + ·0000361t^2$	$·05231 + ·0000722t$
Platinum silver	12·616	$·04726t + ·0000138t^2$	$·04726 + ·0000276t$
Platinum...........	21·309	$·03198t + ·0000063t^2$	$·03198 + ·0000125t$
Lead	11·193	$·02998t + ·0000153t^2$	$·02998 + ·0000306t$

calculated from the proportions of their components. Thermal capacity is, therefore, a physical property which is not likely to be altered to any appreciable extent by small impurities, so that the results obtained by different experimenters agree very closely with each other.

It has been proved[*] that if e be taken to denote "Young's Modulus," and α the mean distance between the centres of two adjacent molecules, $e \times \alpha^7$ is in the case of most metals approximately a constant. From this it would follow that the law of force proved by Maxwell in his experiments on the viscosity of gases[†] to exist between the molecules of a gas is approximately true for solids, accordingly the force between any two adjacent molecules of a solid is approximately as the fifth power of the distance between their centres. Now if we denote the atomic mass by A, the density by Δ, the thermal capacity per unit mass by C_m, and the thermal capacity per unit volume by C_v, we have the following relations :—

$$C_m \times A = \text{a constant};$$

$$C_v = \Delta \times C_m;$$

$$e \times \alpha^7 = \text{a constant};$$

$$\alpha \propto \left(\frac{A}{\Delta}\right)^{\frac{1}{3}}$$

From these relations we obtain—

$$\frac{e}{C_v^{\frac{7}{3}}} = \text{a constant};$$

or that the cube of " Young's Modulus " varies as the seventh power of the thermal capacity per unit volume. This relation was found to hold approximately not merely for the metals here examined, but also in the case of a great many substances for which the values of C_v and e have been determined by other investigators.

Still more approximately is it believed that this relation would hold good if for " Young's Modulus " the bulk-modulus of elasticity were substituted. Denoting the bulk-modulus by e_v, it was found that, within the wide limits of error to which determinations of the value of the bulk-modulus are liable to be affected

$$\frac{e_v}{C_v^{\frac{7}{3}}} = a \text{ constant.}$$

Neither of the above relations can be true for all temperatures, inasmuch as whilst the value of e_v diminishes with rise of temperature, that of C_v increases, but at ordinary temperatures it seems that the bulk-modulus of elasticity in grammes per square centimetre can be calculated from the thermal capacity per unit volume by the formula—

$$e_v = 2071 \times 10^6 C_v^{\frac{7}{3}}$$

The thermal capacity per unit volume increases with the temperature, and the researches of Matthiessen, Fizeau, and others on the one hand, and of Kohlrausch on the other, have shown that there is a like increment in the thermal expansibility and torsionability* of metals. A careful comparison was made of the various increments above mentioned, and it is shown in the paper that whilst the ratio of increase per unit of expansibility with rise of temperature to corresponding value in the case of torsionability† is, within the limits of error of observation, unity, that in which thermal expansibility and thermal capacity are concerned is about two, so that the rate at which thermal expansibility increases with the temperature is about twice the rate at which thermal capacity increases. The rate of increase of both thermal expansibility and thermal capacity varies with the nature of the metal, being greatest for iron and least for platinum.

The so-called " real thermal capacity " of a solid may be found by dividing the thermal capacity of hydrogen per unit mass at constant volume, namely, 2·417, by the atomic mass ; and this part of the capacity will be independent of the temperature. If the " real capacity " be subtracted from the total thermal capacity we obtain that part of the capacity which does vary with the temperature, and which has therefore in this paper been designated the " variable

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* The inverse of " simple rigidity."

† Iron and copper are the only two metals for which the increase of torsionability with rise of temperature has been examined.

thermal capacity." The following table shows that *the rate of increase per unit of thermal expansibility is at* 0° *C., and therefore at any temperature, equal to the increase per unit of the "variable capacity"* :—

Metal.	Rate of increase per unit at 0° C. of "variable thermal capacity" $= C'$.	Rate of increase per unit at 0° C. of thermal expansibility $= E$.	$\dfrac{E}{C'}$.
Iron	·00230	·00309	1·34
Tin................	·00216	·00250	1·16
Aluminium	·00197	·00215	1·09
Lead	·00192	·00174	0·91
Copper	·00127	·00196	1·54
Zinc	·00157	·00170	1·09
Silver.............	·00135	·00155	1·15
Platinum..........	·00064	·00061	0·95

As a consequence of the above-mentioned relations we can from a knowledge of the rate of increase of the "variable thermal capacity" determine the expansibility *at any temperature* between two limits, provided we know the *mean* coefficient of expansion between those limits. Again, should the rate of increase of torsionability prove for all metals, as it is for iron and copper, equal to the rate of increase of expansibility, we shall, by the method of torsional vibrations, be able to determine with any degree of accuracy we please any one of the three rates of increase.

It is shown in the paper that the thermal capacity per unit mass is nearly two and a half times the "real capacity," so that only two-fifths of the whole thermal energy which we may impart to a mass of metal goes towards raising the temperature, the remaining three-fifths being expended in internal and external work. The external work is practically insensible in ordinary cases. Of the internal work, that expended against bulk-elasticity amounts in the limiting cases from $\frac{1}{1000}$ to $\frac{1}{10000}$ of the whole, and, though greater than the external work, is almost insensible; moreover, there seems to be no relationship whatever between the whole thermal capacity per unit volume and the work done against bulk-elasticity.

Raoul Pictet has concluded[*] that the amplitude of the oscillation of molecules around their positions of equilibrium may be taken as corresponding to temperature, and in the case of several metals has shown that

$$T \times \beta \times \alpha = \text{a constant},$$

[*] " Nature," 1879, p. 356.

where T is the melting point temperature reckoned from absolute zero, β the coefficient of linear expansion, and α proportional to the distance between the centres of adjacent molecules. From the above relation combined with those already mentioned we deduce

$$\frac{T \times \beta}{C_v^{\frac{1}{3}}} = \text{a constant};$$

and

$$\frac{T \times \beta}{e_v^{\frac{1}{7}}} = \text{a constant}.$$

The first of these two relations was found to hold good for ten out of twelve metals examined, but for the metals bismuth and antimony the ratio $T\beta : C_v^{\frac{1}{3}}$ is almost exactly *one half* of the ratio obtained for the other metals. It was concluded that for most metals the melting point temperature may be approximately calculated from the formula—

$$T = \cdot 02253 \times \frac{C_v^{\frac{1}{3}}}{\beta}.$$

Where C_v and β represent the mean thermal capacity per unit volume, and coefficient of expansion respectively between 0° C. and 100° C.

The second of the two relations was found also to approximately hold good.

Altogether the following relations have been approximately established by experiment:—

(1) $$\frac{e^{\frac{1}{7}}}{C_v^{\frac{1}{3}}} = \text{a constant},$$

or more probably $$\frac{e_v^{\frac{1}{7}}}{C_v^{\frac{1}{3}}} = \text{a constant};$$

(2) $$\frac{T\beta}{C_v^{\frac{1}{3}}} = \text{a constant},$$

(3) $$\frac{T\beta}{e^{\frac{1}{7}}} = \text{a constant},$$

or more probably $$\frac{T\beta}{e_v^{\frac{1}{7}}} = \text{a constant}.$$

In these relations we may substitute $\frac{\Delta}{A}$ for C_v, where Δ is the density and A the atomic mass.

In the paper will be found a full discussion of the experiments of Joule[*] and Edlund[†] on the thermal effects produced by mechanical stress in metals.

* "Phil. Trans.," 1859, vol. 149, p. 91.
† "Ann. de Phys. und Chemie," Band cxxvi, p. 539.

According to the researches of the latter the *observed* thermal effects of longitudinal stress on a wire is to be found by dividing the *theoretical* thermal effects by 1·61, since part of the work expended on a wire which is stressed longitudinally finds its equivalent in molecular effects which are not thermal. This view seems to be partly supported by some experiments made by the author on the viscosity of metals.

V. "Note on Boiling in a Vessel contained in a Water Bath." By CHARLES TOMLINSON, F.R.S. Received May 31, 1884.

In the "Phil. Trans." for 1673, No. 97, among the "Acta Medica" of Dr. Bartholin, the twelfth is thus stated:—

"A contrivance of making water not boyl in the midst of boyling water, by hanging a narrow-mouth'd glass, half-full of water, in the midst of an Iron Kettle filled with water; whereupon the ambient water may by a strong fire be made to boyl, when as the water in the glass, though it be hot, yet will not boyl at all, though some few bubbles be seen at the bottom, which do all vanish before they come to the top."

In "Rozier's Journal" for 1773, p. 1, is a memoir entitled "Expériences et Phénomènes singuliers sur la Communication de la Chaleur, par M. Braun, de l'Académie de St. Pétersbourg." In this memoir, reference is made to a paper by Olaus Borrichius in the "Memoirs of the Academy of Copenhagen," entitled "Aqua in medio aquæ non ebulliens."

In M. Braun's experiments, a copper vessel was filled with water, and another copper vessel, containing water to the height of two-thirds, was placed in it, so that the level of the water in the outer vessel was above that in the inner. The water in the outer vessel was made to boil violently during upwards of an hour, and the water in the small vessel did not show the least sign of ebullition. It remained in fact 9° (De Lisle's ther.) below the temperature of the water in the outer vessel.

The experiment was also tried in vessels of glass, earthenware, iron, &c., with the same result. Also with different liquids, such as spirits of wine of various densities, contained in both vessels, when the temperature of the liquid in the smaller vessel was from 4° to 12° or 13° below that in the outer vessel. With various kinds of wine, the difference was 4° or 5°; with milk 7°; and with petroleum from 15° to 20°. These results, the author remarks, form a strange paradox, but may possibly be referred to the fact that the outer vessel is immediately in contact with the source of heat.